CHAPTER 4. ECONOMICS OF RECYCLING

INTRODUCTION

Although started as a method of reusing waste materials, recycling of asphalt pavement has proved to be a cost effective method of pavement rehabilitation. When properly selected, all the different types of recycling methods are usually cheaper than the conventional rehabilitation methods, even though the relative savings will depend on the kind of recycling technique used. The primary saving in hot and cold mix recycling comes from savings in the cost of virgin asphalt cement, whereas the savings in hot in-place recycling comes by elimination of transpor-tation cost and use of very little amount of virgin material. The major savings in the case of cold in-place recycling comes by eliminating the need for fuel or emission control system, since the process is done at ambient temperature, elimination of transportation costs, and the addition of only a small percentage of virgin asphalt binder. The objective of this session is to present the economics associated with the use of recycled asphalt materials. Expenditures and cost comparisons with the use of conventional HMA mixes are summarized from available literature.

Estimated price associated with pavement construction, reconstruction and recycling operations are presented in this chapter. These prices have been collected from available literature. Whenever possible, prices collected from literature published in or after 1990 are generally reported. It should be noted that recycling costs have changed over the years because of continual developments in the recycling technology and equipment. If costs for these operations are available from state or local agency records or from local contractors, they should be used instead since a large price variation can be expected depending on the location of the project and the time of construction.

As presented here, the pavement cost is defined as the amount of monies that a contractor must spend for labor, materials, equipment, subcontractors, and overhead to construct, rehabilitate or maintain a pavement structure.[1]

COST AND SAVINGS ASSOCIATED WITH HOT MIX RECYCLING

The cost associated with recycling can be presented on a material cost as well as construction cost basis. Although construction cost may be a more valid approach, an example of material cost comparison is also presented here. This example shows the amount of savings that can be made by using recycled asphalt pavement (RAP) instead of using virgin material.[2] Considering $5 per ton and $120 per ton as average costs of aggregate and liquid asphalt, respectively, the cost of a 100 percent virgin mix with 6 percent asphalt comes out to be $11.90 (see table 4-1). If the contractor uses a half-lane milling machine and hauls the RAP back to the HMA plant, his/her total cost for RAP is $3.70 per ton, considering $1.70 per ton for machine and labor for milling, and $2.00 per ton for trucking cost. Hence the savings, compared to using virgin material, is $8.20 per ton, as shown in table 4-1. Table 4-2 shows the savings in using different percentages of RAP. It should be noted that these savings are in first cost. Limiting life cycle costs, if any, must be considered when using excessive amounts of RAP in recycled mixes. Typical cost savings with hot mix recycling are shown in tables 4-3 and 4-4.

Table 4-1. Comparison of cost for virgin and RAP mix.[2]

Item	Cost per ton ($)	Percent used (%)	Total Cost ($) per ton
Aggregate	5.00	94	4.70
Asphalt Binder	120.00	6	7.20
Virgin Mix			11.90
RAP			
Trucking	2.00		2.00
Milling	1.70		1.70
RAP Mix			3.70
Savings in using 1 ton of RAP instead of 1 ton of virgin mix			8.20

Table 4-2. Savings by using RAP (based on reference 2).

Percent of RAP	Cost/Ton	Savings, $/ton	Savings, %
0%	11.90		
20%	10.26	1.64	14
30%	9.44	2.46	21
40%	8.62	3.28	28
50%	7.80	4.10	34

HOT IN-PLACE RECYCLING

There are three primary types of hot in-place recycling, as recognized by the Asphalt Recycling and Reclaiming Association (ARRA). These are: surface recycling, repaving, and remixing.

Surface recycling to a depth of 25 mm (1 in) and addition of a recycling agent costs approximately $1.25/m^2 ($1.00/yd^2).[3] A cost of approximately $2.05/m^2 ($1.64/yd^2) is required for an additional 25-mm (1-in) overlay. Hence the total cost of recycling and overlaying by two-pass method will be approximately $3.3/m^2 ($2.64/yd^2).[3] In the repaving method, placement of a 25-mm (1-in) overlay along with recycling of the top 25 mm (1 in) of an existing pavement will cost approximately $3.62/m^2 ($2.90/yd^2).[4,5] A maximum of 25 percent cost savings over cold milling and conventional overlaying procedure has been reported.[6] The cost of cutting 25 mm (1 in) and remixing with 10 to 20 percent of virgin aggregate is approximately $2.24/m^2 ($1.79/yd^2).[6] Typical remixing price in Canada is reported to be between $2.78 and $3.70/m^2 for a 50-mm treatment depth (between $2.22 and $2.96/yd^2 for a 2-in treatment depth).[7]

Table 4-3. Summary of cost savings - FHWA survey (1984).

Area	Total Tonnage (1000) 1984	Average Savings Per Ton ($)	Average % Savings vs. 100% New Material(s)	Total Savings ($1000)
Northeast	500	2.80	10	1,400
Southeast	4,000	5.67	20	22,300
North-central	12,000	5.26	18	62,600
South-central	2,000	5.32	20	10,000
Central-western	1,600	5.12	21	8,200
Total	20,000	---	---	104,500
Average	---	4.83	18	---

Table 4-4. Typical cost savings.

Agency	Year(s)	% Average Savings
Florida DOT	1981-1983	24-26
Saskatchwan	1985	20-30
U.S. Corps of Engineers	1986	16
Wisconsin DOT	1980-1985	39-49

In a 101,156 m^2 (121,000 yd^2) repaving job in Florida, it was found that the recycling process used 2.6 trillion joules (2.5 billion BTU) less energy than that required by a conventional method. This was found equivalent to an energy savings of 32 percent.[(8)]

Table 4-5[(6)] presents a recent summary of cost and savings data and case histories. The estimated savings over conventional construction methods ranges from 17 to 50 percent.[(6)]

COLD IN-PLACE RECYCLING

The reported costs of cold in-place recycling are shown in Table 4-6.[(8)] The representative cost varies from approximately $1.71/m^2 ($1.37/yd^2) to $9.87/m^2 ($7.90/yd^2) depending upon many factors such as depth of recycling, equipment type, and thickness of overlay. The reported relative savings of using cold in-place recycling in lieu of conventional construction methods are also shown in table 4-6. The initial savings have varied from 6 to 67 percent.

The mean cost from Oregon DOT cold in-place recycling projects in the 1989-1990 period was reported to be \$2.51/m^2 (\$2.0/yd^2) for a 50-mm (2-in) cold in-place recycling with a chip seal, and about \$1.80/m^2 (\$1.44/yd^2) without a chip seal.[9]

The mean cost for 48 New Mexico cold-in-place recycling projects ranged from \$0.13 to \$0.44/m-cm^2 (\$0.27 to \$0.92/yd-in^2), with a mean of \$0.26/m-cm^2 (\$0.54/yd-in^2).[9] Recycling cost increases with an increase in the use of virgin aggregates.

On a per square meter per cm basis cost of recycling is reduced with an increase in depth of cold in-place recycling. For the New Mexico state projects, the mean cost per square meter per centimeter have been reported to be \$0.31 for 75 mm (\$0.64/yd-in^2 for 3 in), \$0.27 for 85 mm (\$0.56/yd^2-in for 3.4 in), \$0.25 for 10 cm (\$0.52/yd^2-in for 4 in), and \$0.21 for 11.3 cm (\$0.44/yd^2-in for 4.5 in) of cold in-place recycling.[9]

A recent study shows that the CIR savings in New Mexico amount to approximately \$1.90/m^2 (\$1.52/yd^2) in initial cost and \$2.05/m^2 (\$1.64/yd^2) on the basis of life cycle costs. Figure 4-1 shows typical sections resulting from conventional rehabilitation and recycling operations. Cost figures based on initial cost and life cycle cost are also indicated in the figure. The savings on a life cycle basis results from reduced frequency of maintenance for CIR pavements. Generally, maintenance for cracking is required after every four years for mill and overlay projects, whereas maintenance for cracking is required after eight years for CIR projects.

FULL DEPTH RECLAMATION

Cost comparisons of conventional rehabilitation technique and recycling with full depth reclamation and HMA wearing course are given in table 4-7.[10] In this case, the cost of recycling (\$7.25/m^2, \$5.80/yd^2) is less than one half of the conventional reconstruction technique (\$16.12/m^2, \$12.90/yd^2).

GENERAL BENEFITS OF RECYCLING

Apart from savings in materials, recycling saves money by avoiding transportation cost and cost of filling up landfill space. Recycling reuses non-renewable resources. Hence it should be considered even if the cost of recycling is equal to the cost of conventional rehabilitation. Also, in some cases where overlays are restricted to maintaining underpasses, or avoiding raising guard rails, recycling is a better option compared to conventional rehabilitation methods.

Table 4-5. Summary of selected case histories of hot in-place recycled pavements.[6]

Agency/ Date Recycled	Cost Information	Description of Job	HIR Process Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature
Repaving Process						
FAA, Carrabelle, FL 1990	\$4.28/m^2 (\$3.42/yd^2)	Thompson Field Airport. 30 m x 1212m (98 ft x 696 ft) runway	Repave	25 mm/25 mm (1 in/1 in)	Unknown	Unknown
Florida DOT 1979	\$2.99/m^2 (3.39/yd^2). A savings of 25% estimated	US 41, Ft. Myers, FL 3.9 km (2.4 mile), 6-lane. ADT-39,000	Cutler Repave	25mm/19mm (1 in/3/4 in)	EA-SS-1 0.27 1/m^2 (0.06 gal/yd^2)	79^o-121^{o}C(175^{o}F to 250^{o}F)
City of Phoenix 1990	\$3.59/m^2	City collector street. 800 m^2 (10,000 yd$^{2)}$	Cutler Repave	19mm/25mm (3/4 in/1 in)	Yes, Type and quantity Unknown	Unknown
Lee County, Iowa 1990	\$3.41/m^2	Rural roads X-38 and X-48	Cutler Repave	19mm/25mm (3/4 in/1 in)	Elf ETR-1 at 0.36 1/m^2 (0.08 gal/yd^2)	105^{o}C (221^{o}F)
Connecticut DOT 1981	\$4.33/m^2. 16% more than control	Rt. 15 at Westport, Connecticut 4.7 km (2.9 mile), 4-lane divided	Cutler Repave	25mm/25mm (1 in/1 in)	AE-300R 0.36 1/m^2	250^{o}F ± 30^{o}F by spec.
FAA Texarkana, Texas 1986	50 percent savings reported	Airport- 2011 m^2 (6598 ft^2) and 25 yr old	Cutler Repave	25mm/25mm (1in/1 in)	Type unknown 0.54 1/m^2 (0.11 gal/yd^2)	110^{o}C (230^{o}F)
Remixing Process						
Defense Construction Canada* 1989	\$3.58/m^2 for the 40mm/19mm -- \$4.17/m^2 for conv. 50 mm overlay	Airfield pavements at Canadian Forces Base, Edmonton, Alberta, 330,000 m^2 (412,500 yd^2)	Artec Remixer -- Only a small area was remixed	40mm/50mm (1.6 in/2 in) overlaid later; or 40mm/19mm (1.6 in/0.75 in) repave	RJO #3 at 0.4 1/m^2 (0.08 gal/yd^2)	120^{o}C (248^{o}F) behind paver was targeted value
Texas DOT 1991	\$2.15/m^2 for recycling portion only	IH-10 and SH-87 near Beaumont	Wirtgen Remixer	25mm to 31mm	ARA-1	About 116^{0}C(240^{o}F)

Table 4-5. Summary of selected case histories of hot in-place recycled pavements (continued).[6]

Agency/ Date Recycled	Cost Information	Description of Job	HIR Process Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature
Repaving Process						
Mississippi SHD 1990	Unknown. 40% savings reported	55 lane-km (34 lane-mile) of IH-59 in Lauderdale County	Wirtgen Remixer	38 mm + 15 kg/m^2 of new mix	Yes, unknown	110ºC (230ºF)
British Columbia Ministry of Highways* 1989	\$1.70/m^2 for recycling only	Trans-Canada Highway (Rt 1) near Vancouver, 126 lane-km (78 lane-mile)	Artec and Taisei Remixers	38 mm to 63 mm (no new material added)	Unknown	105ºC (221^0F) minimum
Texas DOT 1987	\$3.05/m^2 a savings of 34% over conventional	US 259 in Lone Star. Major arterial carrying heavy trucks	Cutler Remixer	38 mm + 17 kg/m^2 new mix	AC-5 used with new mix	93ºF (200ºF) behind screed
Texas DOT 1989	\$2.57/m^2 including 30 kg/m^2 of new mix	IH-20 from Louisiana, border to FM450, 51 km, ADT-18,000 20% Trucks	Wirtgen Remixer	38 mm + 30 kg/m^2 new mix	ARA-1 at 0 to 0.71 1/m^2	110ºC (230ºF)
Oregon DOT 1987	17% savings estimated	82nd Ave from N.E. Wasco to S.E. Division a 5-lane major arterial	Taisei Remixer	Up to 50mm + various new mix	Non-emulsified product	Unknown
Texas DOT 1981	\$1.59/m^2 including recycling, rejuv. agent and admixture	US 59 near Lufkin, 20,000 ADT	Wirtgen Remixer	50-38 mm + 20% new mix	ARA-1 at 0.1 0.45 1/m^2 (0.09 gal/yd^2)	107ºC (225ºF)
Louisiana DOT 1990	\$4.59/m^2 including recycling, rejuv. agent and admixture	US 90 from LA 99 to Jennings	Wirtgen Remixer	38 mm + 30 kg/m^2 new mix	ARA-1 at 0.9 l/m^2.. Elf AES-300RP used in a short section	

Note:

* Cost for jobs in Canada given in Canadian dollars.

Table 4-6. Full and partial depth cold in-place recycling cost differences.[8]

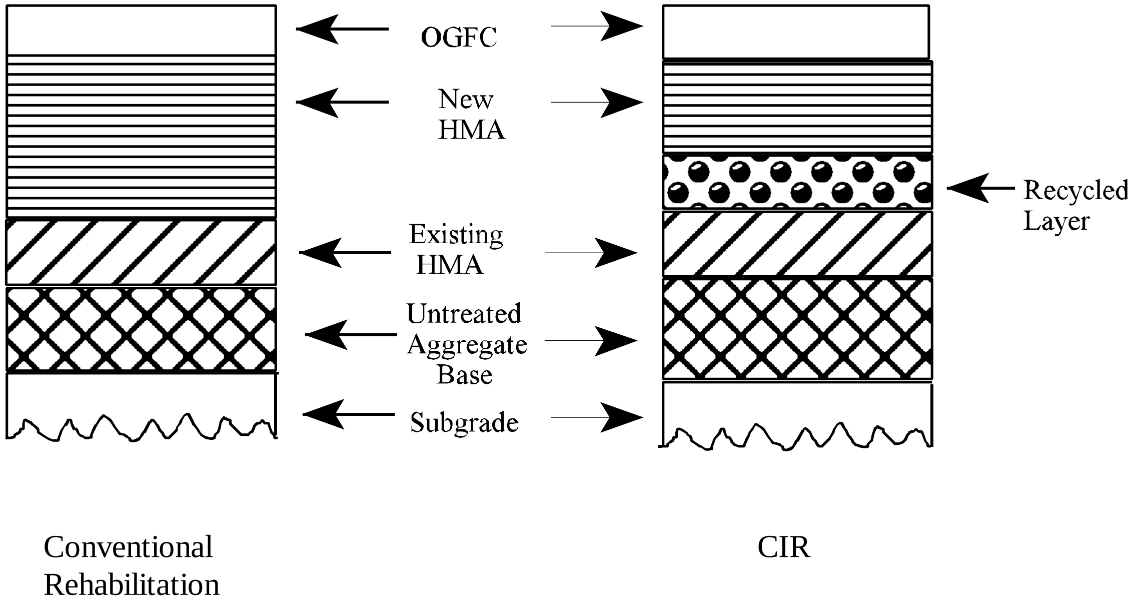
Agency	Year	Cost Difference (%)[a]		Cold In-Place Recycling ($)	
		Range	Rep. Value	Range	Rep. Value ($)
California	1979-83	15-43	31	16.16-26.73/Mg (14.71-24.32/ton)	22.15/Mg (20.16/ton)
California			37		24.17/Mg (22.00/ton)
California	1980		21		6.46/m^2 (5.17/yd^2)
Illinois	1982				4.75/m^2 (3.80/yd^2)
Indiana	1976			13.13-24.17/Mg (11.95-22.00/ton)	
Iowa	1988		67		7.58/Mg (6.90/ton)
Kansas	1977		53		
Kansas	1988				
Missouri	1978		50		
Montana	1978		21		23.72/Mg (21.59/ton)
New Mexico[b]	1984-86			1.31-2.5/m^2 (1.05-2.00/yd^2)	1.75/m^2 (1.40/yd^2)
N. Carolina[c]	1977		6		4.99/m^2 (3.99/yd^2)
Oklahoma	1979				4.32/m^2 (3.46/yd^2)
Oregon	1984		24	1.99-3.02/m^2 (1.81-2.42/ yd^2)	2.50/m^2 (2.00/yd^2)
Pennsylvania	1983		16		
Vermont	1978		28		9.87/m^2 (7.90/yd^2)
Vermont	1982		31		1.71/m^2 (1.37/yd^2)
Wisconsin	1978				0.14/m^2-cm (0.29/yd^2-in)
FHWA					5.9/m^2 (4.72/yd^2)

Notes:

[a] Relative to commonly used rehabilitation alternatives used by identified states.

[b] Personal communication with D. Hanson (1987).

[c] Cost increase on one project.



Initial Construction Cost:

Savings	Maximum	Minimum	Average
$/lane-km	14,296	1,593	7,094
$/square-m	2.81	0.53	1.90

Life Cycle Cost:

Rehab. Option	Initial Costs ($)	Maintenance Cost ($)	Total Cost ($)
Mill and Overlay (total)	8.780	0.314	9.090
CIR (total)	6.880	0.159	7.040
Cost Savings with CIR	1.900	0.155	2.050

Figure 4-1. Typical sections for conventional and recycled pavement.

Table 4-7. Cost comparison (full depth reclamation versus conventional reconstruction).[10]

Option	**Cost**
Fully reconstruct road: 1) excavate existing 75 mm (3 in) pavement and 45 cm (18 in) base gravel; 2) Place, grade and compact 45 cm (18 in) new gravel; 3) Pave with 65 mm (2½ in) HMA	\$16.12/m^2 (\$12.19/yd^2)
Full Depth Reclamation: 1) Full depth reclamation of existing pavement and base gravel with addition (twice) of liquid calcium chloride; 2) Add 50 mm (2 in) additional gravel; 3) Pave with 65 mm (2½ in) HMA	\$7.25/m^2 (\$5.80/yd^2)

SUMMARY

A review of current literature shows that savings up to 40, 50, 55 and 67 percent can be achieved by using hot mix, hot in-place, cold in-place recycling, and full depth reclamation, respectively. These savings are achieved when one of the recycling methods is used in place of conventional method or some other recycling method. In addition to the material and construction cost savings, significant amount of cost savings (in terms of user costs) can be realized by the reduced interruptions in traffic flow when compared with conventional rehabilitation techniques. Recycling can be used to rejuvenate a pavement or correct mix deficiency and conserve material and energy—options not available with the conventional paving techniques. A conventional overlay may require upgrading shoulders to maintain profile, raising guard rails to maintain the minimum safety standard, and restrict overlays below the bridges to maintain underpass height. On the other hand, recycling can effectively be used to maintain the highway geometry and thus resulting in substantial overall savings as well.

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